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PREDICTION OF TRANSIONOSPHERIC SIGNAL TIME DELAYS USING CORRELATIVE TECHNIQUES

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Communications/ADP Laboratory

December 1977

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Excess time delays of transionospheric radio signals introduce ranging errors in satellite-navigation and radar systems, which are directly proportional to the total electron content (TEC) along the propagation path. Correlations of TEC values (based on linear regression analysis) at Fort Monmouth, NJ (40.18°N, 74.06°W), Richmond, FL (25.60°N, 80.40°W) were previously determined. The correlation analysis was performed at monthly and daily intervals for winter periods during the quiet phase of the solar cycle.

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Average regression lines obtained by the analysis were then used to try to determine TEC at Richmond, assuming the availability of TEC in Fort Monmouth. In most cases, the "predicted" TEC was within one standard deviation of actual observed data.

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PREDICTION OF TRANSIONOSPHERIC SIGNAL TIME DELAYS USING CORRELATIVE TECHNIQUES

INTRODUCTION

The effects of ionization along the satellite-to-ground signal-ray-path on the propagation time of such a signal was previously discussed. [1] The excess time delay introduced by the ionization is directly proportional to the total electron content (TEC) along the signal path. In view of the stringent accuracy requirement of modern satellite-navigation and radar systems, the excess time delay must be compensated for either by real-time measurement or through empirical modeling techniques. The former requires that the user possess dual frequency reception capabilities, while the latter (which utilizes a single frequency) depends on how well TEC and its temporal and spatial variability can be modeled and/or predicted. For improved accuracy, the forecasting techniques should be supported by periodic updating of data (preferably in real time) at specified locations. The question arises as to the extent of the geographic area, surrounding a station having real-time TEC-determinating capabilities, within which TEC values could be interpolated with acceptable accuracy. In other words, could TEC be determined at location A if real-time measurement was taken at a different location, B, and what would be the geographic constraints on A and B?

To this end, a specific investigation designed to determine the correlation (based on linear regression analysis) between TEC values at Fort Monmouth, NJ (40.18°N, 74.06°W), and at Richmond, Florida (25.60°N, 80.40°W), was undertaken. [2] Beacon transmissions from the geostationary Applications Technology Satellites ATS-6 [3], [4] were used to determine the TEC at the two stations by means of the Faraday rotation technique.

The subionospheric points for the two stations [i.e., the geographic locations where the ray paths to the ATS-6 (located at 94°W) intersect a "mean" altitude of 420 Km] were 36.5°N, 76.6°W and 23.6°N, 81.6°W, respectively. Thus, the "representative" TEC for the two stations was separated by $\sim 13^{\circ}$ in latitude and by 5° in longitude (corresponding to a 20-minute difference in local time.)

The correlation data indicated that TEC, or equivalently, ionospheric signal time-delays, are highly correlatable at the two locations. When daily data sets for the two locales were compared at approximately the same local time the correlation coefficients were, in general, $\gtrsim 0.9$.

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[1] H. Soicher, "Ionospheric and Plasmaspheric Effects in Satellite Navigation Systems," IEEE Trans. Antennas & Propagation, Vol. AP-25, No. 5, Sep 77.

[2] H. Soicher, "Spatial Correlation of Transionospheric Signal-Time-Delay," IEEE Trans. Antennas & Propagation, March 1978 (In the Press).

[3] K. Davies, R.B. Fritz, and T.B. Gray, "Measurement of Columnar Electron Contents of the Ionosphere and Plasmasphere," J. Geophysical Research, Vol. 81, p. 16, June 1, 1976.

[4] H. Soicher, "The ATS-6 Radio Beacon Experiment," Nature, Vol. 253, pp. 252-254, January 24, 1975.

The next phase of the investigation was the effort to determine whether it is possible to accurately predict TEC at Richmond from TEC at Fort Monmouth, using average regression lines obtained for the two data sets. The technique employed was as follows: Average monthly regression lines were computed. In one case, average slopes as well as average intercepts of the regression lines of monthly intervals were computed. In a second case, average slopes were computed while the intercepts were forced to pass through a common data point for the two sets at 0200 for each day. Having determined the average regression lines, TEC at Richmond was calculated for a given TEC at Fort Monmouth. The deviation (D), of the calculated TEC at Richmond from its actual value at a particular time is then determined. This deviation, D, is then divided by the monthly TEC standard deviation value at the same time. The average absolute value of this ratio, i.e., $\left|\frac{D}{\sigma}\right|$ was then computed for each day. The results using average slopes and intercepts of the monthly regression lines is shown in Fig. 1. The results using average slopes and forcing the average regression to pass through common points at 0200, is shown in Fig. 2. Also shown in Figs. 1 and 2 is the number of data points available for the analysis for each day (data is available at 15-minute intervals; ninety-six data points signifies a full day's data availability. Data is sometimes missing, due to turn-off of the satellites beacons).

The results using average slopes and intercepts of the monthly regression lines, but for the time period 1300-2100 UT, when the maximum diurnal TEC values occur are shown in Fig. 3. Similarly, the results using average slopes and forcing the average regression lines to pass through common points at 0200 are shown in Fig. 4.

DISCUSSION

As Fig. 1 indicates, the daily average of the ratios $\left|\frac{D}{\sigma}\right| = \frac{1}{N} \sum_{i=1}^{N} \left|\frac{D_i}{\sigma_i}\right|$ is, for the most part, smaller than one, i.e., on the average, the deviation of the computed Richmond TEC values, is, in general, within the monthly standard deviation of the Richmond data. The diurnal behavior of the ratio is such that the ratio is higher during the night (when σ is small) than during the day. Some of the high values of this ratio are attributable to ionospheric effects during magnetically active periods, e.g., on September 15 & 18, 1974, large enhancements of TEC were observed in response to magnetic sudden commencements; on March 11, the K_p index ranged from 4^o to 7^-. The results of the figure also indicate that the ratio appears larger during the equinoctial period (September, March) than during the winter and spring months. This is observed despite the fact that the standard deviation during the equinoctial months was considerably higher than during the other months.

The ratio, in general, does not change substantially (as compared to the above case) when the average regression slopes are forced to pass through the actual data points at the two locations at 0200, as may be seen by comparing Figures 2 and 1. This happens despite the fact that $|D|$ is smaller during the night (although σ is also small compared to its day values.) The disadvantage of using this technique for possible operational application, is of course, the inavailability of any data points at the locale where the predictions are to be made.

Since total signal time-delays are largest during the day and thus, introduce significant errors in navigation and radar systems, it is appropriate to examine the ratio $\frac{|D|}{\sigma}$ during the time when TEC is diurnally larger, i.e., between 1300 and 2100 UT. During the day $|D|$ and σ are generally larger than during the night. Figures 3 and 4 indicate that the ratio $\frac{|D|}{\sigma}$, obtained by average regression lines computed by the two techniques for the day period, are substantially lower than the corresponding ratios for the full diurnal periods (Figs. 1 and 2). The fact that the bulk of the data indicates that the ratio falls below 1 is encouraging since both correlation methods yield "predicted" TEC values that fall within the monthly standard deviation of the data during the time period when the presence of TEC poses the source of largest error.

CONCLUSIONS

The high correlation of signal time-delay variation at two locales separated by $\sim 13^{\circ}$ in latitude and $\sim 5^{\circ}$ in longitude, prompted the examination as to whether time-delay data at one locale may be "predicted" if continuous corresponding data were available at the other locale. The correlation is high, in part, due to the 24 hour periodicity of the data. It is precisely this periodicity, however, that gives the "prediction" technique employed here its accuracy. The variation of the time delay is the highly correlatable quantity, and thus, the whole data set— if available, should be used in the prediction scheme.

Monthly average regression lines were used in the analysis. The slopes of the average regression lines were almost identical for September, April, and May, but differed within ±20% from this value for January, February, and March. The average intercepts of the line of regression were considerably more scattered.

For the most part, the deviation of the "predicted" data from the observed data was within one standard deviation of the monthly data set. For daytime periods, when the error introduced by the time-delay is greatest, the ratio $|D|/\sigma$ was even lower. When the average regression line for the entire period considered was calculated (i.e., the average of six monthly averages), the bulk of the "predicted" data was still within one standard deviation of the monthly data set. The ratio is often high during time periods characterized by ionospheric disturbances.

Since the monthly value standard deviation is $\sim 25\%$ of the absolute value of the time delay, the method of prediction outlined here appears to have the capability of correcting the time delay due to the ionosphere to within $\sim 25\%$. Future efforts will be directed towards evaluation of correlation and prediction of ionospheric signal time-delays at stations of greater geographic and local time separation.

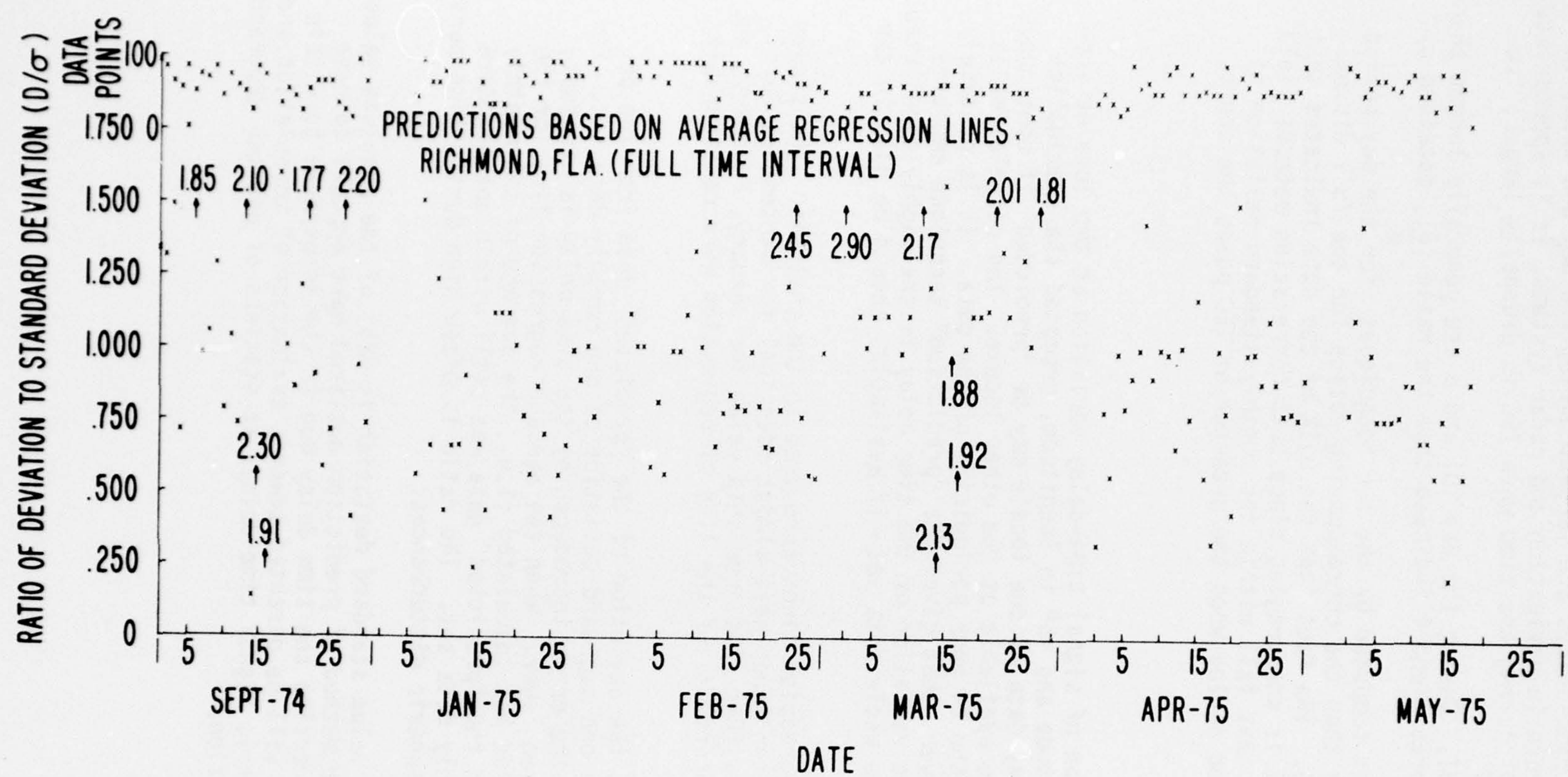

Fig. 1

The variation of the ratio $|D|/\sigma$ for Richmond, FL, for the time period September 1974, and Jan 75—May 75, calculated for full diurnal periods by average regression lines obtained by Fort Monmouth, NJ—Richmond, FL data sets. $|D| \equiv$ diurnal average of the deviations of the computed TEC values from observed ones; $\sigma \equiv$ monthly standard deviation of the Richmond data. Also indicated are the number of TEC values at 15-minute intervals used in the analysis.

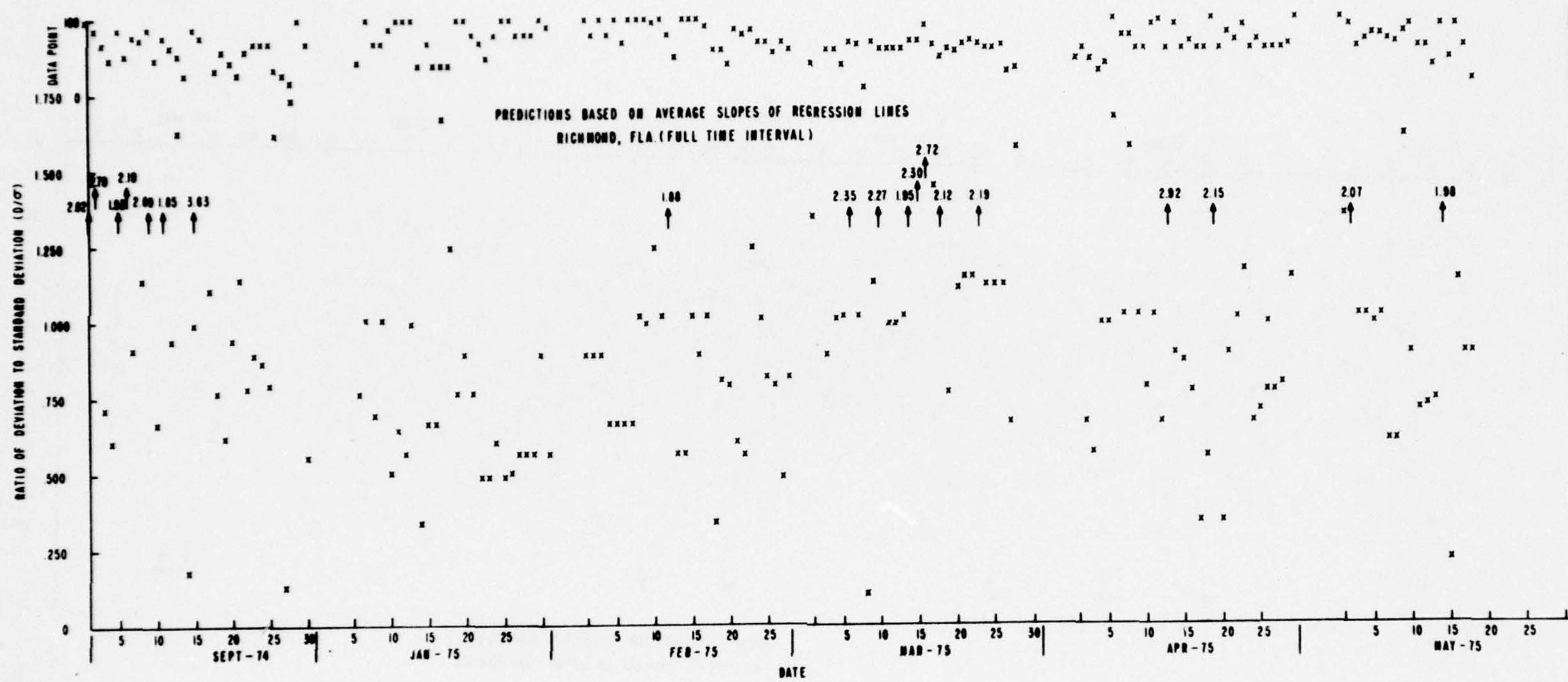

Fig. 2

Same as Fig. 1, except the average calculated regression slopes are forced to pass through common TEC values at 0200 UT.

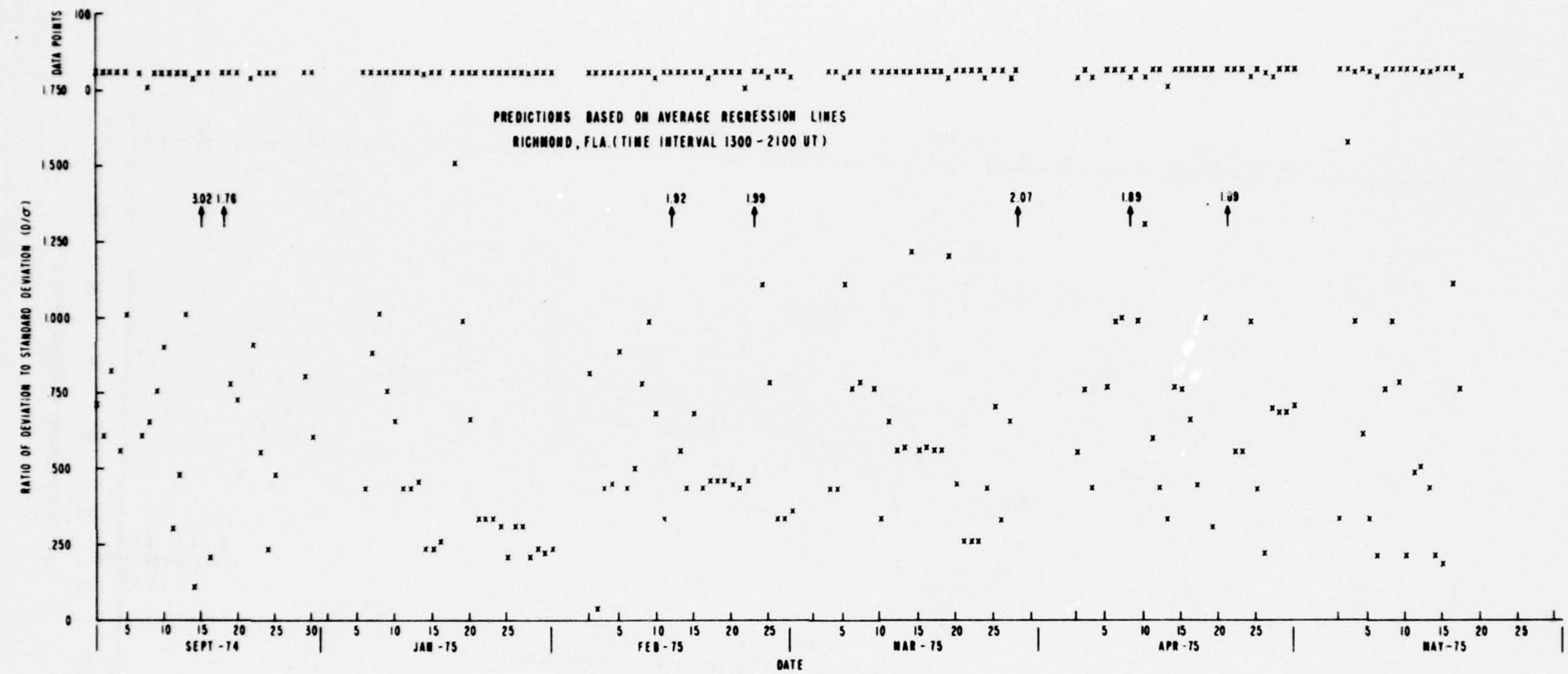

Fig. 3

Same as Fig. 1, except that the ratios are computed only for the time period 1300-2100 UT.

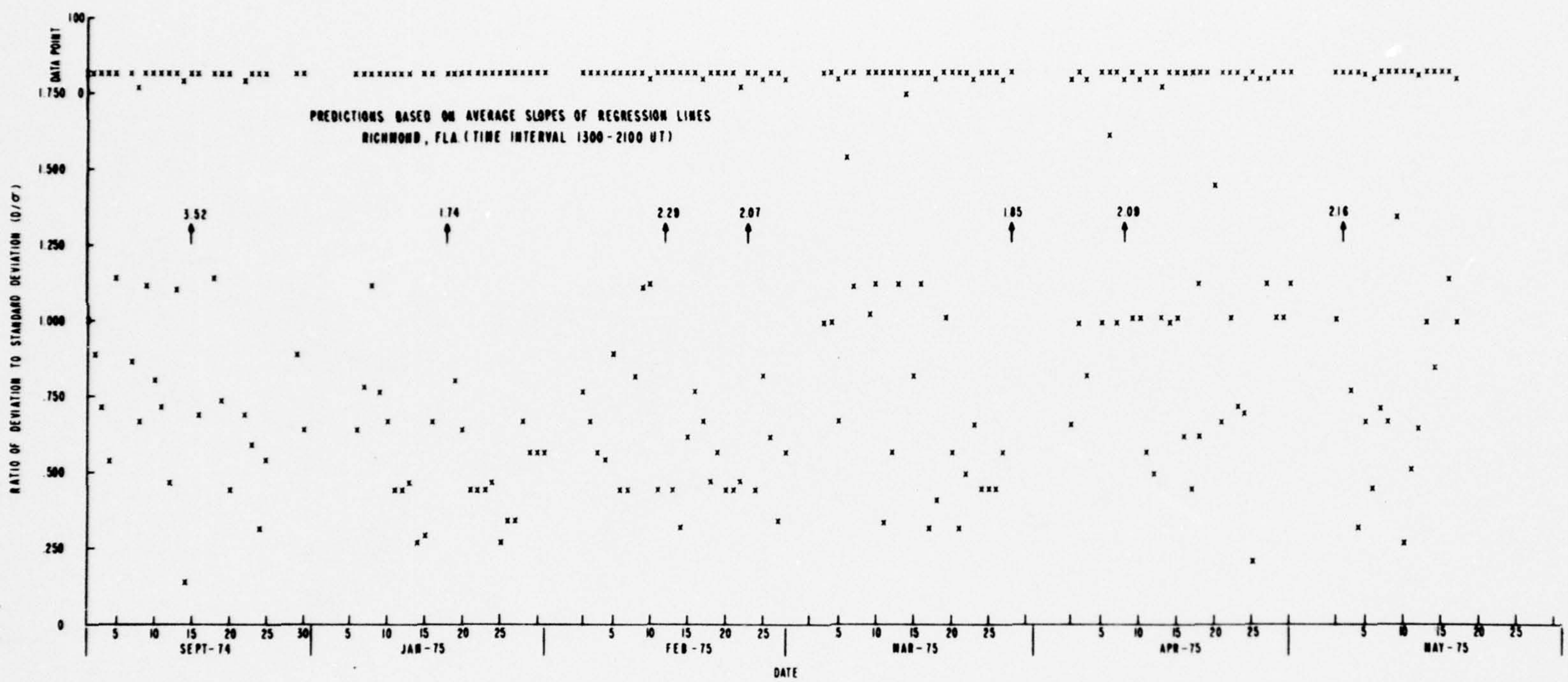

Fig. 4

Same as Fig. 2, except that the ratios are computed only for the time period 1300-2100 UT.